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A NEW 350 MS ISOMER IN  $^{125}\text{La}$  AND LOW ENERGY  
INTRINSIC  
STATES IN A=133,131,129,127,125 La ISOTOPES

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By means of the HIGISOL technique, the A=125 mass chain was studied via  $\beta^+$ /EC decay of  $^{125}\text{Ce}$  and a new  $(350^{+60}_{-40})\text{ms}$  isomer was definitely assigned to  $^{125}\text{La}$  based on conversion electron measurements.

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## 1. Introduction

This work belongs to a series of investigations initiated at SARA [1, 2, 3] and devoted to the study of low-lying excited levels in neutron-deficient odd La fed via  $\beta^+$ /EC decay of Ce isotopes. Although a wealth of data on the rotational bands has been obtained from in-beam spectroscopy using heavy ion induced reactions, the levels at low excitation energy with low spin remain poorly known. The nuclei of this so called transition region around A=130 have a prolate-triaxial shape which has been rather well interpreted with different theoretical models. Recently, lifetime measurements [4] of levels of the decoupled  $\pi h_{11/2}$  band [5], both in  $^{127}\text{La}$  and  $^{125}\text{La}$ , have reinforced the picture of a quasiparticle coupled to a rigid triaxial core ( $\beta_2 \simeq 0.28$ ,  $\gamma \simeq 20$  deg). The ground state is the bandhead  $11/2^-$  in  $^{127}\text{La}$  whereas in  $^{125}\text{La}$  it has  $I^\pi = 3/2^+$ , similar to  $^{129,131}\text{La}$ .

At first, two  $\gamma$  transitions were observed in the  $\beta^+$ /EC decay of  $^{125}\text{Ce}$  [1] and then a preliminary level scheme was constructed as reported

in [6]. More recently, we have suggested the existence of a  $(0.4 \pm 0.2)$ s isomer in the  $A=125$  mass chain [7]. The aim of the present work was mainly, by means of conversion electron and coincidence measurements, to assign the  $Z$  of this isomer and to try to shed light on the  $^{125}\text{La}$  level scheme at low energy.

## 2. Experiment

The  $^{125}\text{Ce}$  activity was produced via the  $^{94}\text{Mo}(^{36}\text{Ar}, 3p2n)$  reaction followed by  $\beta^+$ /EC decay and studied on-line after mass-separation. The  $^{94}\text{Mo}$  target, a self-supporting foil of  $3.0 \text{ mg/cm}^2$  and 97.6% enrichment, was bombarded with 175 MeV  $^{36}\text{Ar}^{8+}$  ions (300 part.nA) from the K=130 Jyväskylä cyclotron. Reaction products were mass-separated using the HIGISOL technique developed originally at SARA for heavy ions induced fusion-evaporation reactions [8]. The system recently implemented at the Jyväskylä IGISOL facility gives readily a mass-separated yield of about 1 ion/s/mbarn/10 part.nA [9] independent of the chemical and physical properties of the elements. The 40 keV beam of  $A=125$  radioactive ions was impinging on a 6.4 mm wide movable tape at the center of the first coil of the ELLI spectrometer described in more details in reference [10]. ELLI is a hybrid design combining the features of a magnetic transporter and a high resolution, 4 mm thick and  $300 \text{ mm}^2$  area Si(Li) detector placed at the center of the second coil. The electron energy calibration was carried out with a  $^{133}\text{Ba}$  source and the energy resolution was typically 2.5 keV at 320 keV. A low energy Ge detector ( $10 \text{ mm} \times 1000 \text{ mm}^2$ , resolution 530 eV at 53 keV) was placed outside the vacuum chamber, on the symmetry axis of the spectrometer and only 10 mm from the implantation spot.

To allow growth and decay sequences of the activities, the cyclotron beam was pulsed ( $T_{ON} = T_{OFF} = 10 \text{ s}$ ). Both time-sequenced singles spectra (e-T, X-T) and e-X-t coincidence data were acquired and stored on exabyte tape using the VENLA data acquisition system [11].

## 3. Results

A typical conversion electron spectrum measured with the ELLI spectrometer is shown in figure 1. Most of the lines of the  $A=125$  mass chain were identified, except three lines at 68.2, 101.7 and 106.2 keV energies. From e-X data, there is clear evidence of a coincidence between the 68.1 keV electron line and both  $K_{\alpha}$ - and  $K_{\beta}$ -La X rays indicating that conversion takes place in the elements La. Therefore this line can be attributed to the K conversion of the 107.0 keV transition since the K-binding energy is 38.9 keV. The two other lines (101.7 and 106.2 keV) can be assigned to L- and M-conversion

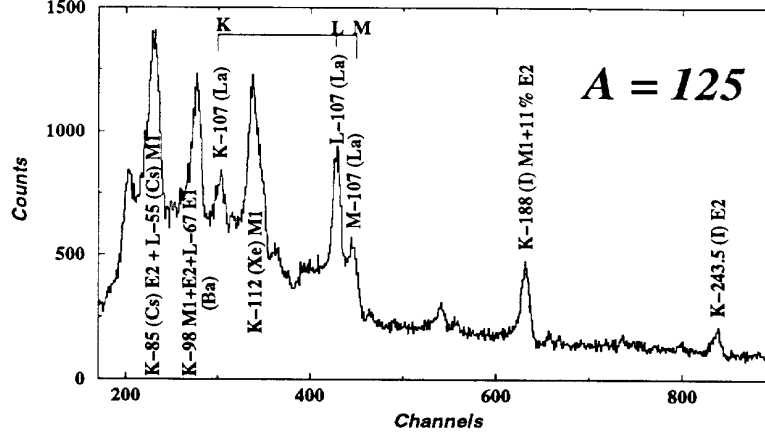


Fig. 1. Partial conversion electron spectrum measured with the ELLI spectrometer.

lines of the same transition on the basis of similar arguments. Moreover, an accurate determination of energy differences between these electron lines gives  $E_K - E_L = (33.5 \pm 0.3)$  keV and  $E_L - E_M = (4.5 \pm 0.3)$  keV in perfect agreement with theoretical values, 33.24 and 4.53 keV respectively in case of La.

To achieve a precise determination of internal conversion coefficients (ICC), it is of crucial importance to get with good accuracy the intensities of both  $\gamma$  rays and conversion electrons. The efficiency of ELLI being very sensitive to the localisation of the beam spot of HIGISOL, we have used an internal calibration procedure by means of transitions of well known multipolarities in the  $A=125$  mass chain. The efficiency curves were then constrained to these particular points.

For the 107 keV transition we could deduce the following ICC values :  $\alpha_K = 2.5 \pm 1.5$ ,  $\alpha_L = 8.1 \pm 3.2$ ,  $\alpha_M = 2.4 \pm 1.0$  and associated subshell ratios. Comparing with theoretical values calculated from reference [12] and [13], the E3 nature can be assigned unambiguously to this transition.

From the e-T data, we could extract the time distributions (growth and decay) for all conversion electron lines of the spectrum presented in figure 1. The K-, L- and M-lines of the 107 keV transition exhibit similar time behaviour, they have been analysed separately considering feeding of the isomer from both  $^{125}\text{Ce}$   $\beta^+$ /EC decay and direct reaction production. The half-life deduced from the fitting procedure of the sum spectrum shown in figure 2, gives for  $^{125m}\text{La}$ ,  $T_{1/2} = (350^{+60}_{-40})$  ms corroborating the result

we got from  $K_{\alpha}$ -La X rays analysis [7]. For the slow component the half-life value  $T_{1/2} = (9.9 \pm 0.5)$  s is also in good agreement with previous results [14].

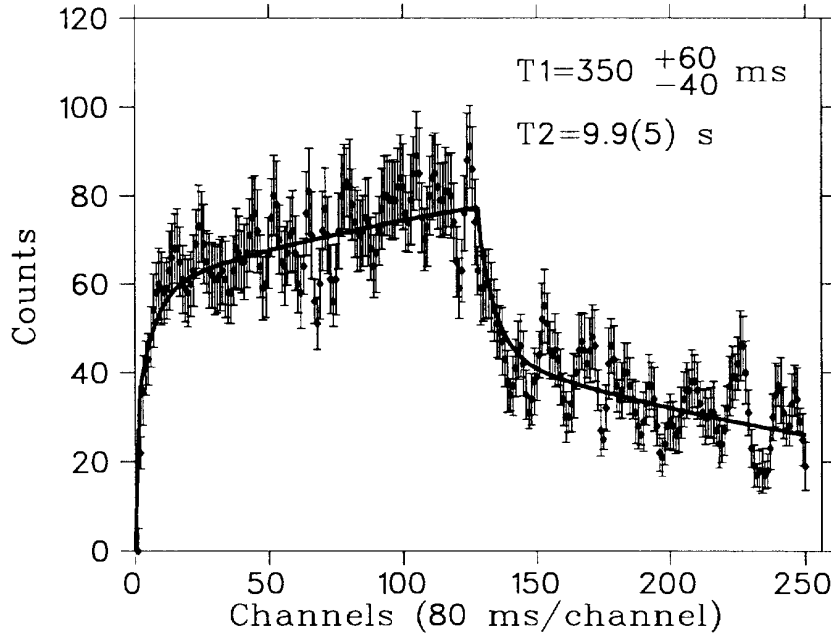


Fig. 2. Growth and decay of singles K+L+M electrons of the 107.0 keV E3 transition. The curve is calculated with two components + long-lived contamination.

#### 4. Discussion

Unless creating a new level at an excitation energy slightly above 107 keV, it is at present not possible to place this isomeric transition in the existing level schemes deduced either from in beam work [4] or from  $\beta^+$ /EC decay of 10 s  $^{125}\text{Ce}$  [6]. From  $\beta$ -delayed proton emission [14],  $I^\pi = 5/2^+$  was suggested for the g.s. of  $^{125}\text{Ce}$  contrary to the Nilsson model which predicts the last neutron to occupy the  $1/2^+[411]$  deformed orbit for  $\beta_2 = 0.28$ . As in  $^{127}\text{Ce}$  and  $^{129}\text{Ce}$ , we may also have a close lying  $7/2^-$  state and therefore more data are needed, especially on  $\beta$  branches and coincidences between electrons and low energy  $\gamma$  rays, to shed light on the  $\beta$  decay scheme. For the 107 keV transition, the hindrance factor value which can be derived from the ratio of experimental half-life to its Weisskopf estimate is  $F_W = 1.3 \pm 0.2$ .

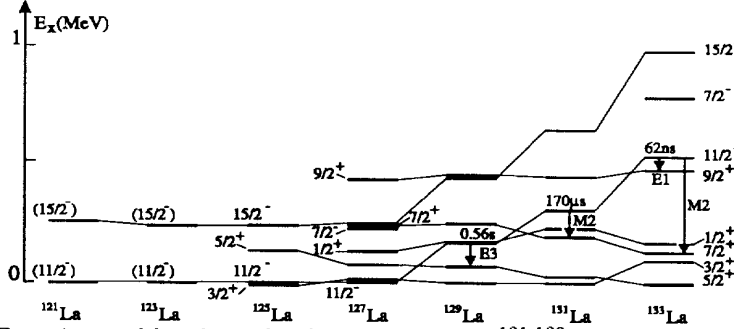


Fig. 3. Experimental low lying levels in odd La. In  $^{121,123}\text{La}$ , the g.s. is assumed ( $11/2^-$ ) and the  $9/2^+$  is not reported (excitation energy unknown) [2, 3, 4, 15] and refs therein.

This is a typical value for an E3 transition in this nuclear region and this indicates that we are dealing with a rather pure single particle transition  $\pi 11/2^- \rightarrow \pi 5/2^+$  (e.g.  $F_W = 2.0$  in  $^{129}\text{La}$  and  $F_W = 2.1$  in  $^{123}\text{Cs}$ ).

Some low lying states of odd La ( $121 \leq A \leq 133$ ) are presented in figure 3. The systematics shows the gradual increase of deformation with decreasing neutron number down to  $N=70$ , which is reflected by the  $15/2^- - 11/2^-$  energy spacing. For lighter isotopes the deformation seems to stabilize and there is no obvious fingerprint of subshell closure at  $N=64$  for  $^{121}\text{La}$ .

In  $^{129,131,133}\text{La}$ , isomerism is due to the interplay between the  $\pi h_{11/2}$  orbital and the positive parity orbitals  $\pi 1g_{7/2}$ ,  $\pi 2d_{5/2}$  and  $\pi 2d_{3/2}$ . The g.s. of  $^{125}\text{La}$  is proposed to have  $I^\pi = 3/2^+$  [4] (as in  $^{129}\text{La}$  and  $^{131}\text{La}$ ) and its structure is strongly mixed with a dominant  $d_{5/2}$  component as was shown from both IBMF-2 calculations [3] and the core quasiparticle coupling model [4]. In this isotope, the  $11/2^-$  level is proposed at an excitation energy of  $\simeq 9$  keV and thus  $\beta$  decay would strongly compete with the isomeric transition. It is expected that because valence protons are filling the lower part of the  $h_{11/2}$  shell and valence neutrons are at the  $h_{11/2}$  midshell, conflicting shape driving forces will result. Therefore the downsloping of the  $11/2^-$  level with decreasing  $N$  could be interrupted around  $N=70$  as it is the case in the odd Pr isotopes.

Additional data on  $^{125}\text{La}$  are needed and the continuation of  $\beta^+/\text{EC}$  decay studies on more n-deficient isotopes i.e.  $^{123}\text{La}$  and  $^{121}\text{La}$  is also highly desirable to gain information on absolute excitation energies of the positive and negative close lying intrinsic levels in these isotopes.

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